DØnote 4374-CONF

Search for non-SM Light Higgs Boson in the $h \to \gamma\gamma$ Channel at DØ in Run II

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A search for non-SM light Higgs boson with an enhanced branching fraction into photons in $p\bar{p}$ collisions at the Fermilab Tevatron is presented using $\approx 190\,\mathrm{pb}^{-1}$ of Run II DØ data taken between April 2002 and September 2003. In the absence of an evidence for a signal, we set upper 95% CL limits on the diphoton branching fraction as a function of the Higgs mass in the Fermiophobic and Topcolor Higgs scenarios.

Preliminary Results for Winter 2004 Conferences

I. MOTIVATION

Diphotons is a very clean signature, which makes it promising and important especially for the hadron collider environment. In the Standard Model (SM) Higgs boson decays mostly to b-quark, W, or Z boson pairs depending on the mass range, while its $\gamma\gamma$ decay branching fraction is too small ($10^{-3} - 10^{-4}$), to be able to use diphotons to probe SM Higgs at the Tevatron [1]. However many extensions of the SM allow enhanced $\gamma\gamma$ decay rate of the Higgs largely due to suppressed couplings to fermions [2–6]. These models originate in various theoretical frameworks and differ in their quantitative predictions. According to [1], we should be prepared for any branching fraction even up to 100%.

From the experimental point of view, it is convenient to perform a search as a function of branching fraction and reduce the list of enhancement possibilities to just two scenarios based on dominant production mechanisms. The two scenarios are called Fermiophobic Higgs and Topcolor Higgs. Fermiophobic Higgs does not couple to fermions at all and is dominantly produced by the W/Z fusion and in association with W/Z. Topcolor Higgs couples to the top quark (the only non-zero fermion coupling) and therefore in addition to W/Z fusion and W/Z associated production, can also be produced in gluon fusion which increases the total production rate significantly. Higgs couplings with W/Z (and with the top quark in case of Topcolor Higgs) are assummed to be the same as in the Standard Model.

Note that the terms 'Fermiophobic Higgs' and 'Topcolor Higgs' in this note refer to the two mentioned scenarios (classes of models) while in the literature they may denote more specific models.

II. DATASET

The data used for this analysis were collected with the DØ detector between April 2002 and September 2003. The data sample corresponds to a total integrated luminosity of $191 \pm 13\,\mathrm{pb}^{-1}$. Initially, the trigger requirement for this data sample was two electromagnetic objects with $E_T > 10$ GeV. The trigger requirement was later raised to two electromagnetic objects with $E_T > 20$ GeV.

III. DIPHOTON EVENT SELECTION

Offline, we select events with two reconstructed EM objects with $E_T > 25$ GeV in the Central Calorimeter (CC) or End- Calorimeter (EC) in the detector η range of $|\eta| < 1.05$ and $1.5 < |\eta| < 2.4$, respectively. EM objects are required to pass photon ID: calorimeter energy isolation, EM energy fraction, calorimeter shower shape, and track isolation cuts, and to have no associated track with this EM object. Finally, we apply analysis optimization cut: p_T of the diphoton system ($p_T^{\gamma\gamma}$) is required to be above 35 GeV. The selected events are divided into three categories in the analysis:

- CC-CC events (both photons are in Central Calorimeter);
- CC-EC events (one photons is in Central Calorimeter, another in End Calorimeter);
- EC-EC events (both photons are in End Calorimeter).

IV. BACKGROUNDS

Major sources of background to $h \to \gamma\gamma$ are:

- Drell-Yan $Z/\gamma^* \to ee$ events in which both electrons are misidentified as photons. Drell-Yan background is estimated from data by relating the diphoton mass spectrum to the dielectron mass spectrum using tracking information.
- Direct diphoton events. We estimate this background from Monte Carlo.
- QCD events that in the final state have: a photon and a jet misidentified as photon or two jets misidentified as photons. QCD background is estimated from data. The background sample was obtained by removing shower shape quality cut and then the photon misidentification rate was applied to this sample.

A. Efficiencies and Misidentification Rates

$\gamma\gamma$ background calculations rely on the measurements of:

- photon misidentification rate;
- tracking efficiency;
- EMID efficiency.

1. Photon Misidentification Rate

By a 'misidentified' photon we mean a photon that comes from either a hadronic jet rich in EM content (due to a secondary π^0 (or other neutral mesons with large branching fractions to photons such as η)) or from a photon in γ+jets events. Usually it is only the former that is referred to as a 'misidentified' photon. However, in this note we do not make a distinction between the two. Our method of QCD background estimation allows to consider them together. Photons from direct diphoton events, on the other hand, need to be treated separately. Photon misidentification rate is defined as number of photons divided by the number of EM objects in which shower shape quality cut was removed. We select the data sample that consists of events with exactly one EM object. To ensure that this sample is dominated by the QCD jet and γ production, we veto the events with more than one EM object (potential $Z/\gamma^* \to ee$ and direct diphotons), as well as events with the Missing Transverse Energy above 15 GeV (potential $W \to e\nu$). Photon misidentification rate is 0.1 in CC and ~0.15-0.3 in EC.

2. Tracking Efficiency

We define Tracking Efficiency $\epsilon(track)$ as the efficiency of finding a track and matching it to an electron. We calculate tracking efficiency using $Z \to ee$ events. In case of matching criteria on ϕ, η, and E/p (the ratio of the calorimeter energy over the track momentum) variables tracking efficiency is found to be:

ϵ(track) = 81.6 ± 0.6 (stat) ± 4.4 (syst)% (CC);
ϵ(track) = 78.8 ± 1.2 (stat) ± 4.4 (syst)% (EC-south(inner): η=[1.5,1.9]);
ϵ(track) = 56.3 ± 1.5 (stat) ± 4.4 (syst)% (EC-south(outer): η=[1.9,2.4]);
ϵ(track) = 78.2 ± 1.2 (stat) ± 4.4 (syst)% (EC-north(inner): η=[-1.9,-1.5]);
ϵ(track) = 61.4 ± 1.6 (stat) ± 4.4 (syst)% (EC-north(outer): η=[-2.4,-1.9]).

In case of spatial only match tracking efficiencies are:
ϵ(track) = 97.0 ± 0.1 (stat) ± 3.0 (syst)% (CC);
ϵ(track) = 71.0 ± 1.0 (stat) ± 4.4 (syst)% (EC).

To suppress $Z/\gamma^* \to ee$ background in the Z-resonance region spatial-only match is used, whereas outside this region matching includes E/p match.

3. EMID Efficiency

EMID Efficiency $\epsilon(EM)$ is defined as probability for a Loose EM object to pass the shower shape and track isolation cuts. We estimate it from the data using the Z-mass peak and find:

ϵ(EM) = 84.9 ± 0.7 (stat) ± 2.3 (syst)% (CC)
ϵ(EM) = 91.3 ± 0.5 (stat) ± 2.0 (syst)% (EC)

CC EMID efficiency was calculated using CC-CC events, and EC EMID efficiency was calculated using CC-EC events.

V. MASS DISTRIBUTIONS AND EVENT YIELDS

The $\gamma\gamma$ invariant mass distributions for the data and predicted background, as well as the event yields are shown in Fig. 1 for the CC-CC, CC-EC, and EC-EC event topologies. The $\gamma\gamma$ invariant mass spectrum from data is in agreement with the expected SM background.

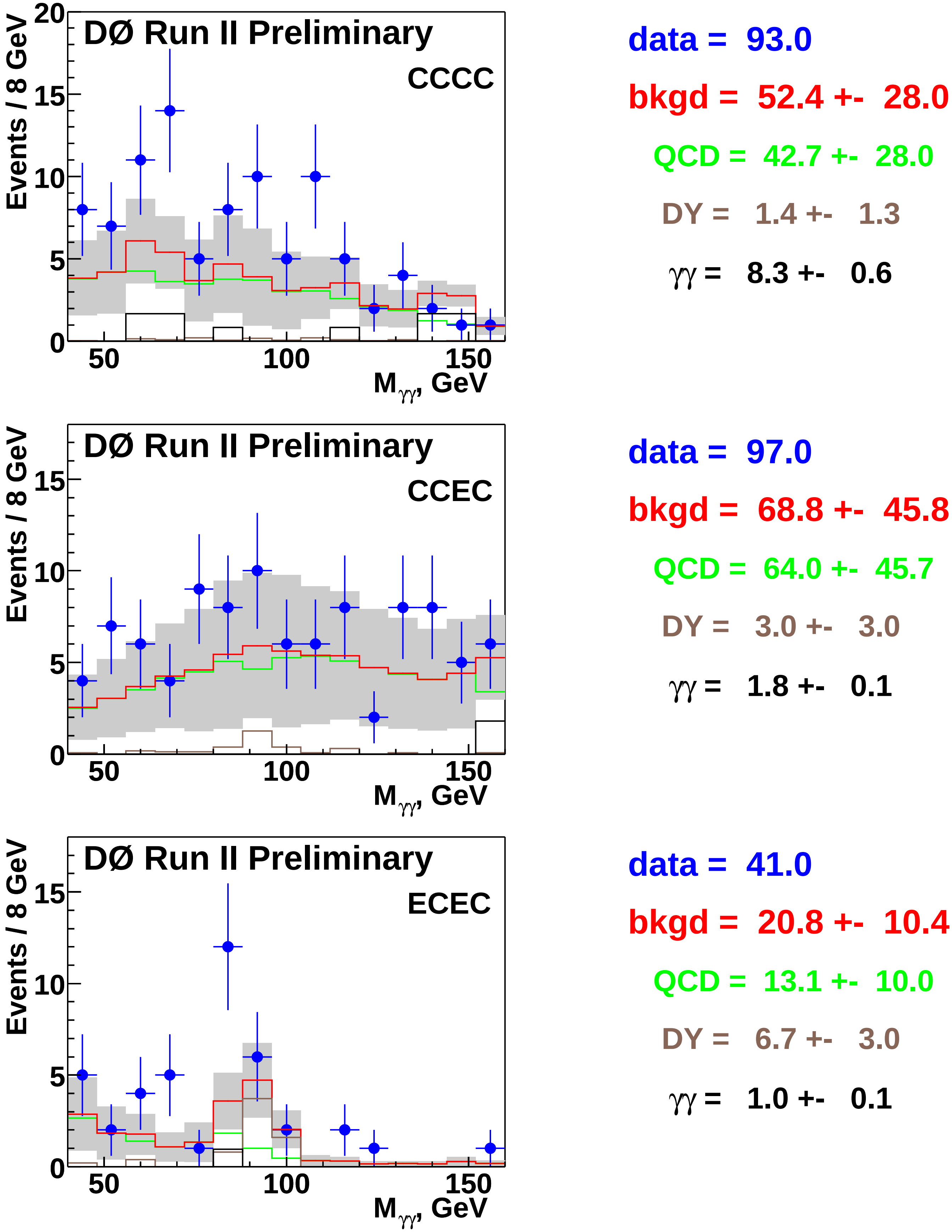

FIG. 1: Diphoton invariant mass distributions and event yields for different event topologies. Blue points – $\gamma\gamma$ spectrum observed in data, read line – total SM background (shaded rectangles indicate background errors), green line – QCD background, brown line – Drell-Yan background, black line – direct diphoton background.

VI. LIMITS ON THE $h \to \gamma\gamma$ BRANCHING FRACTION

We perform counting experiment in the optimized sliding mass window [9] for 60,...,150 GeV Higgs mass points and set B($h \to \gamma\gamma$) limits following Bayesian approach. The mass window is calculated using Higgs Monte Carlo samples and corrected for the effects of detector resolution in the real data using $Z \to ee$ events. Mass window values are listed in Table I. Signal acceptance of the mass window as well as acceptance due to η, p_T, and $p_T^{\gamma\gamma}$ cuts is shown in

	Fermiphobic Higgs	
	CCCC	CCEC
$M_{\rm h}$, GeV	Mass Window, GeV	Mass Window, GeV
60	6.5 ± 0.2	5.2 ± 0.1
70	6.6 ± 0.2	6.5 ± 0.2
80	7.6 ± 0.2	6.9 ± 0.2
90	7.9 ± 0.2	7.5 ± 0.2
100	8.8 ± 0.2	7.1 ± 0.2
110	8.8 ± 0.2	8.5 ± 0.2
120	9.2 ± 0.2	8.1 ± 0.2
130	9.3 ± 0.2	9.4 ± 0.3
140	10.6 ± 0.3	9.8 ± 0.3
150	10.3 ± 0.2	10.3 ± 0.3
	Topcolor Higgs	
	CCCC	CCEC
$M_{\rm h}$, GeV	Mass Window, GeV	Mass Window, GeV
60	6.7 ± 0.2	5.6 ± 0.2
70	6.6 ± 0.2	6.9 ± 0.2
80	7.7 ± 0.2	6.8 ± 0.2
90	8.4 ± 0.2	7.7 ± 0.2
100	8.7 ± 0.2	7.8 ± 0.2
110	9.5 ± 0.2	8.8 ± 0.2
120	9.7 ± 0.2	9.1 ± 0.3
130	10.2 ± 0.2	9.9 ± 0.3
140	10.7 ± 0.3	9.8 ± 0.3
150	10.7 ± 0.3	10.2 ± 0.3

TABLE I: Mass window used for counting experiment

Table II. Dominant systematic error on the signal comes from the luminosity measurement (6.5%), while dominant systematic error on the background comes from the measurement of photon misidentification rate (30%). Figure 2 shows 95% CL limits on the B($h \to \gamma\gamma$) as a function of Higgs mass. The limits are set using CC-CC and CC-EC events. Comparison is made with DØ Run I [7] and LEP results [8] as well as Run II Monte Carlo studies for Tevatron [9] based on Run I efficiencies and misidentification rates.

VII. CONCLUSIONS

A search for non-SM light Higgs boson with an enhanced branching fraction into photons was performed using $\approx 190\,\mathrm{pb}^{-1}$ of data collected by the DØ experiment in Run II of the Fermilab Tevatron. We set an upper 95% CL limits on the diphoton branching fraction as a function of Higgs mass for Fermiophobic and Topcolor Higgs scenarios.

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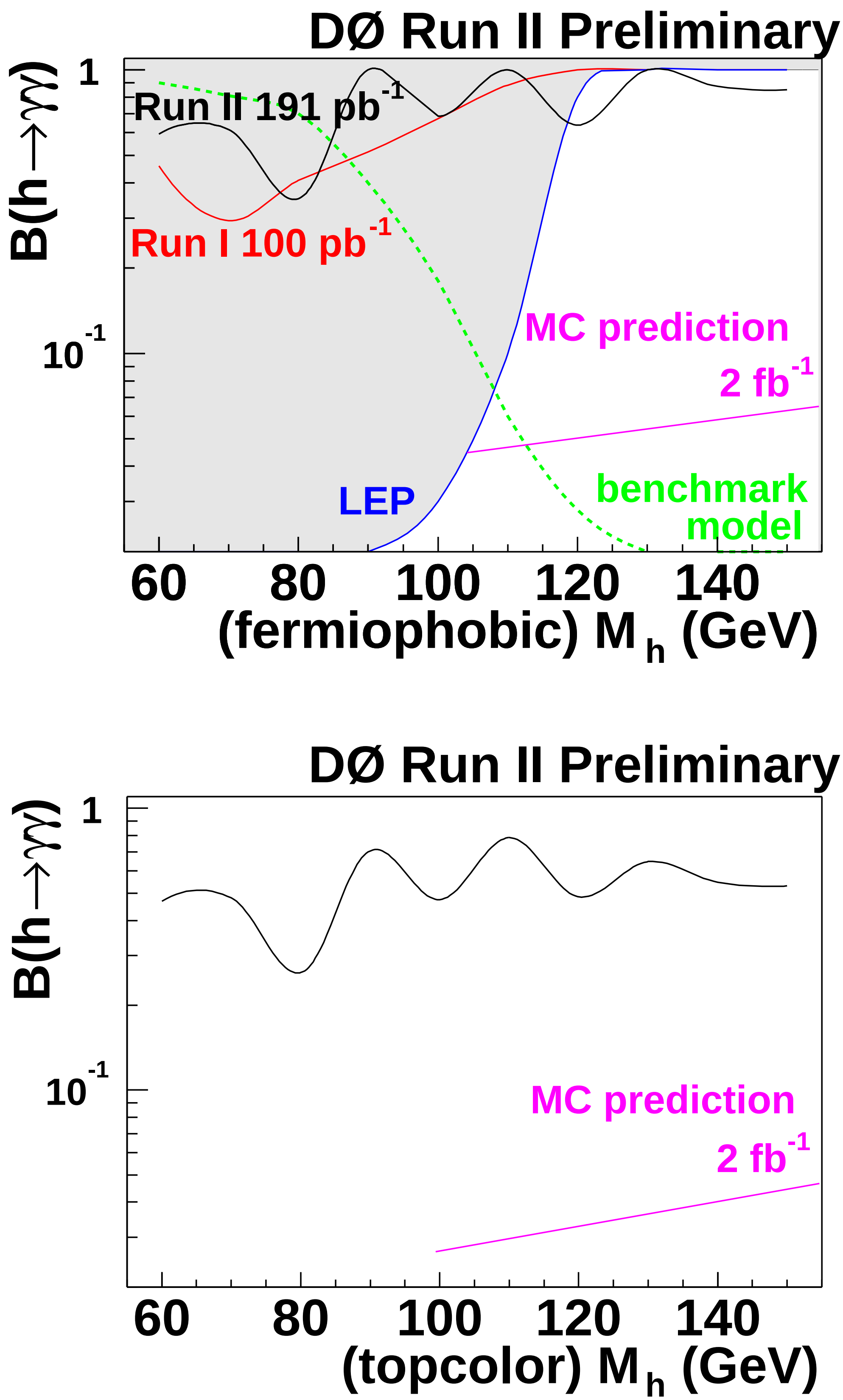

FIG. 2: 95% CL limits on the Higgs decay branching fraction into photons as a function of mass (black curve). Top plot – fermiophobic Higgs scenario, bottom plot – topcolor Higgs scenario. On the top plot exclusion contours from DØ Run I [7] (red) and LEP [8] (blue) are overlaid. The region excluded by LEP is indicated with grey. Green points – theoretical curve for benchmark fermiophobic Higgs model [10]. Magenta lines show 2 fb^{-1} Monte Carlo prediction for Tevatron Run II [9] based on Run I DØ and CDF efficiencies and misidentification rates.

	Fermiphobic Higgs			
	CCCC	CCCC	CCEC	CCEC
$M_{\rm h}$, GeV	Mass Window	η, p_T, $p_T^{\gamma\gamma}$	Mass Window	η, p_T, $p_T^{\gamma\gamma}$
60	82.2 ± 2.0 %	9.4 ± 0.3 %	79.1 ± 3.9 %	2.4 ± 0.2 %
70	81.8 ± 1.5 %	13.6 ± 0.4 %	84.5 ± 2.9 %	3.4 ± 0.2 %
80	82.7 ± 2.3 %	16.8 ± 0.5 %	80.0 ± 2.6 %	4.9 ± 0.3 %
90	80.7 ± 1.8 %	19.9 ± 0.5 %	84.7 ± 2.6 %	5.9 ± 0.3 %
100	79.9 ± 2.1 %	23.2 ± 0.5 %	80.3 ± 2.4 %	7.7 ± 0.3 %
110	79.1 ± 1.9 %	25.6 ± 0.5 %	80.8 ± 2.5 %	8.3 ± 0.3 %
120	80.1 ± 2.4 %	27.1 ± 0.5 %	79.8 ± 3.3 %	9.6 ± 0.4 %
130	77.5 ± 1.8 %	29.3 ± 0.5 %	80.7 ± 2.6 %	10.0 ± 0.3 %
140	78.5 ± 1.9 %	29.7 ± 0.5 %	80.4 ± 2.9 %	10.9 ± 0.3 %
150	76.8 ± 2.1 %	31.7 ± 0.5 %	81.3 ± 2.3 %	11.2 ± 0.3 %
	Topcolor Higgs			
	CCCC	CCCC	CCEC	CCEC
$M_{\rm h}$, GeV	Mass Window	η, p_T, $p_T^{\gamma\gamma}$	Mass Window	η, p_T, $p_T^{\gamma\gamma}$
60	85.6 ± 3.0 %	3.8 ± 0.2 %	82.4 ± 5.5 %	0.8 ± 0.1 %
70	83.0 ± 1.9 %	5.8 ± 0.2 %	84.5 ± 5.5 %	1.3 ± 0.1 %
80	83.4 ± 1.9 %	7.5 ± 0.3 %	78.2 ± 3.4 %	2.0 ± 0.1 %
90	81.5 ± 2.2 %	9.4 ± 0.3 %	85.4 ± 3.9 %	2.8 ± 0.2 %
100	78.5 ± 2.3 %	11.2 ± 0.3 %	84.7 ± 3.5 %	3.6 ± 0.2 %
110	81.5 ± 1.4 %	11.9 ± 0.3 %	80.5 ± 3.4 %	4.0 ± 0.2 %
120	82.2 ± 1.8 %	13.0 ± 0.4 %	84.9 ± 3.0 %	4.6 ± 0.2 %
130	81.1 ± 1.7 %	14.1 ± 0.4 %	83.5 ± 3.3 %	5.2 ± 0.2 %
140	78.4 ± 1.7 %	14.8 ± 0.4 %	79.1 ± 3.1 %	5.6 ± 0.2 %
150	77.7 ± 1.9 %	15.7 ± 0.4 %	79.5 ± 3.0 %	5.7 ± 0.2 %

TABLE II: Signal acceptance due to mass window and η, p_T, $p_T^{\gamma\gamma}$ cuts.

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